

Global analysis for determining polarized parton distribution functions in the nucleon

Asymmetry Analysis Collaboration (AAC)
<http://spin.riken.bnl.gov/aac/>

Shunzo Kumano

High Energy Accelerator Research Organization (KEK)

shunzo.kumano@kek.jp

<http://research.kek.jp/people/kumanos/>

with Masanori Hirai (KEK) and Naohito Saito (Kyoto)

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Determination of polarized parton distribution Functions (PDFs)

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Status of PDF determinations

Unpolarized PDFs in the nucleon ★ ★ ★ ★

Investigated by 3 major groups (CTEQ, GRV, MRST).

Well studied from small x to large x in the wide range of Q^2 .

The details are known. (Recent studies: NNLO, QED, error analysis, $s - \bar{s}$, ...)

“Polarized” PDFs in the nucleon ★ ★

Investigated by several groups (GS, GRSV, LSS, AAC, BB, ...).

Available data are limited (DIS) at this stage.

New data from HERMES, JLab, COMPASS, RHIC-Spin, ...

Process/ Experiment	Leading order subprocess	Parton behaviour probed
DIS ($\mu N \rightarrow \mu X$) $F_2^{\mu p}, F_2^{\mu d}, F_2^{\mu n}/F_2^{\mu p}$ (SLAC, BCDMS, NMC, E665)*	$\gamma^* q \rightarrow q$	Four structure functions \rightarrow $u + \bar{u}$ $d + \bar{d}$ $\bar{u} + \bar{d}$ s (assumed $= \bar{s}$), but only $\int x g(x, Q_0^2) dx \simeq 0.35$ and $\int (\bar{d} - \bar{u}) dx \simeq 0.1$
DIS ($\nu N \rightarrow \mu X$) $F_2^{\nu N}, x F_3^{\nu N}$ (CCFR)*	$W^* q \rightarrow q'$	
DIS (small x) F_2^{ep} (H1, ZEUS)*	$\gamma^*(Z^*) q \rightarrow q$	λ ($x\bar{q} \sim x^{-\lambda_s}$, $xg \sim x^{-\lambda_g}$)
DIS (F_L) NMC, HERA	$\gamma^* g \rightarrow q\bar{q}$	g
$\ell N \rightarrow c\bar{c}X$ F_2^c (EMC; H1, ZEUS)*	$\gamma^* c \rightarrow c$	c ($x \gtrsim 0.01$; $x \lesssim 0.01$)
$\nu N \rightarrow \mu^+ \mu^- X$ (CCFR)*	$W^* s \rightarrow c \rightarrow \mu^+$	$s \approx \frac{1}{4}(\bar{u} + \bar{d})$
$pN \rightarrow \gamma X$ (WA70*, UA6, E706, ...)	$qg \rightarrow \gamma q$	g at $x \simeq 2p_T/\sqrt{s} \rightarrow$ $x \approx 0.2 - 0.6$
$pN \rightarrow \mu^+ \mu^- X$ (E605, E772)*	$q\bar{q} \rightarrow \gamma^*$	$\bar{q} = \dots(1-x)^{\eta s}$
$pp, pn \rightarrow \mu^+ \mu^- X$ (E866, NA51)*	$u\bar{u}, d\bar{d} \rightarrow \gamma^*$ $u\bar{d}, d\bar{u} \rightarrow \gamma^*$	$\bar{u} - \bar{d}$ ($0.04 \lesssim x \lesssim 0.3$)
$ep, en \rightarrow e\pi X$ (HERMES)	$\gamma^* q \rightarrow q$ with $q = u, d, \bar{u}, \bar{d}$	$\bar{u} - \bar{d}$ ($0.04 \lesssim x \lesssim 0.2$)
$p\bar{p} \rightarrow WX(ZX)$ (UA1, UA2; CDF, D0) $\rightarrow \ell^\pm$ asym (CDF)*	$ud \rightarrow W$	u, d at $x \simeq M_W/\sqrt{s} \rightarrow$ $x \approx 0.13; 0.05$ slope of u/d at $x \approx 0.05 - 0.1$
$p\bar{p} \rightarrow t\bar{t}X$ (CDF, D0)	$q\bar{q}, gg \rightarrow t\bar{t}$	q, g at $x \gtrsim 2m_t/\sqrt{s} \simeq 0.2$
$p\bar{p} \rightarrow \text{jet} + X$ (CDF, D0)	$gg, qg, qq \rightarrow 2j$	q, g at $x \simeq 2E_T/\sqrt{s} \rightarrow$ $x \approx 0.05 - 0.5$

Situation of data for polarized PDFs

Available data

HERMES, COMPASS, Jlab in progress

→ Neutrino factory: 10~15 years later ?

→ Small-x: eRHIC ?

→ Charm: eRHIC ?

→ RHIC
J-PARC ?

→ pp: RHIC

→ pp: RHIC

RHIC-Spin program
should play an important
role in determining
polarized PDFs.

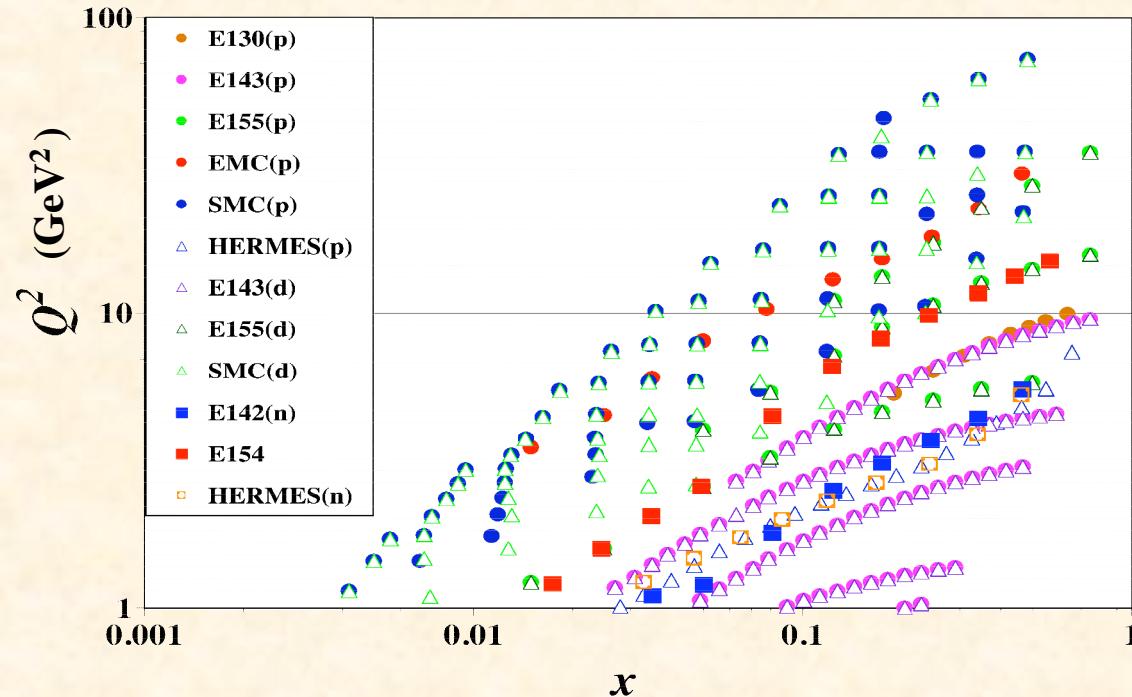
Table from MRST,
(hep-ph-9803445)
Eur. Phys. J. C4 (1998) 463.

Polarized PDF analysis by AAC (Asymmetry Analysis Collaboration)

<http://spin.riken.bnl.gov/aac/>

- Y. Goto et al., Phys. Rev. D62 (2000) 034017.
- M. Hirai, SK, N. Saito, Phys. Rev. D69 (2004) 054021.
- research in progress.

Experimental data on spin asymmetry $A_1(x, Q^2)$



Total data 399 points
($Q^2 > 1 \text{ GeV}^2$)

- A_1 data
 - Proton : E130, E143, EMC, SMC, HERMES, E155
 - Deuteron: E143, E155, SMC, HERMES, COMPASS
 - Neutron : E142, E154, HERMES, JLab

Analysis Method

$i = u_v, d_v, \bar{q}, g$

Initial distributions $\Delta f_i(x, Q_0^2) = A_i x^{\alpha_i} (1 + \gamma_i x^{\lambda_i}) f_i(x, Q_0^2)$

$$A_1 \simeq \frac{g_1}{F_1} = g_1 \frac{2x(1+R)}{F_2}$$

$$R = \frac{F_L}{2x F_1} = \frac{F_2 - 2x F_1}{2x F_1}$$

$A_i, \alpha_i, \gamma_i, \lambda_i$: parameters

χ^2 fit to the A_1 data [p, n (${}^3\text{He}$), d] $\chi^2 = \sum_i \frac{(A_{1i}^{\text{data}} - A_{1i}^{\text{calc}})^2}{(\sigma_{A_{1i}}^{\text{data}})^2}$

We analyzed the data with the following conditions.

- unpolarized PDF GRV98
- initial Q^2 $Q_0^2 = 1 \text{ GeV}^2$
- number of flavor $N_f = 3$

- positivity $|\Delta f(x)| \leq f(x)$
- antiquark flavor $\Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s}$

The error of a distribution $F(x)$ is given by

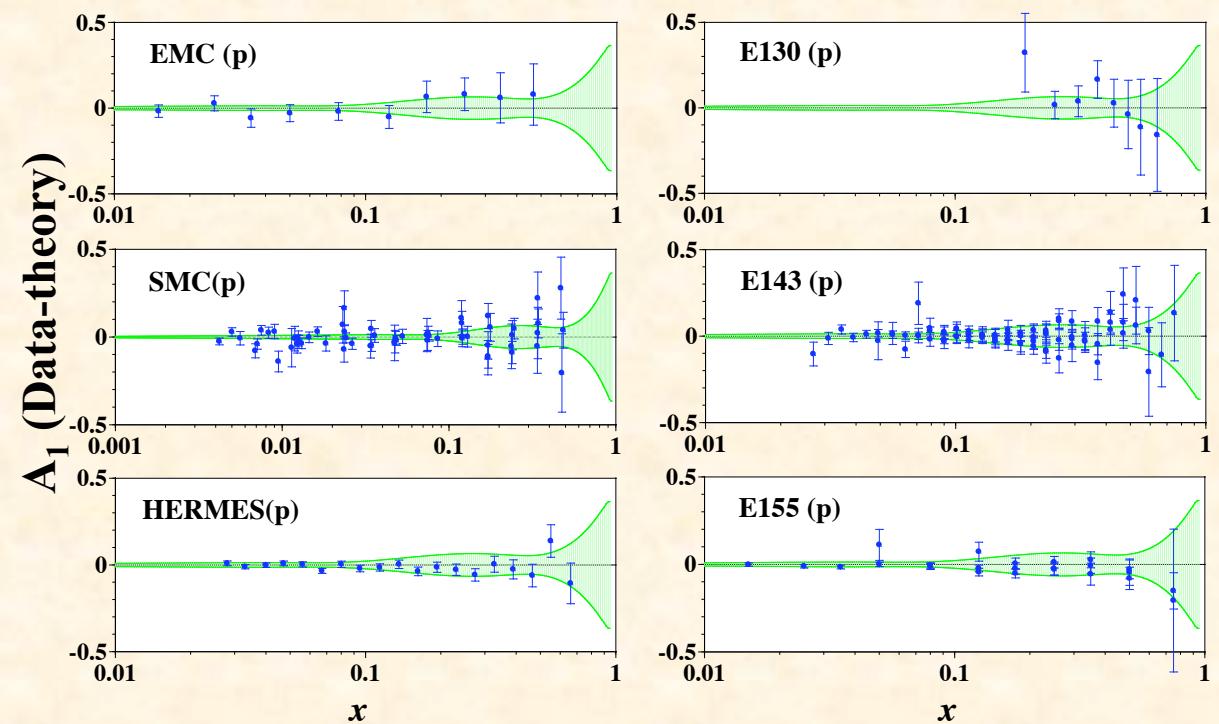
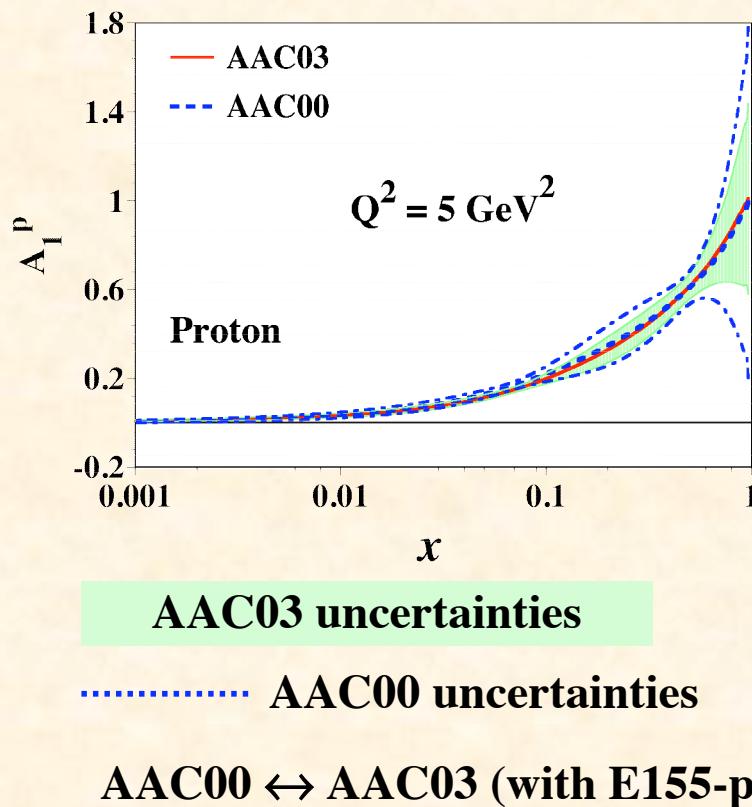
$$[\delta F(x)]^2 = \Delta \chi^2 \sum_{i,j} \frac{\partial F(x)}{\partial \xi_i} H^{-1}_{ij} \frac{\partial F(x)}{\partial \xi_j}$$

H = Hessian
 ξ_i = parameter

→ results: $\chi_{\min}^2 / \text{d.o.f.} = 0.893$

Spin asymmetry A_1^p

- Precise data (E155-proton) reduce asymmetry uncertainties
- Agreement with polarized DIS data
 - Quark and antiquark distributions are constrained
 - Gluon distribution needs other constraints



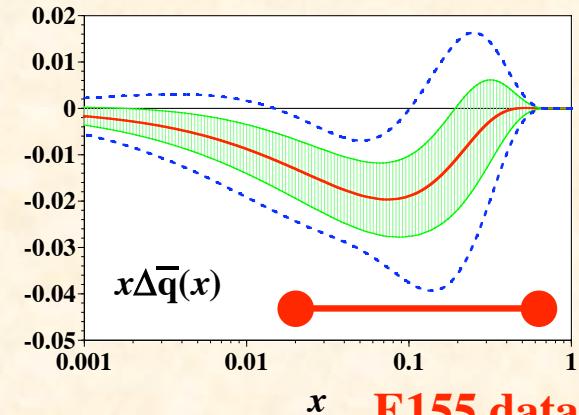
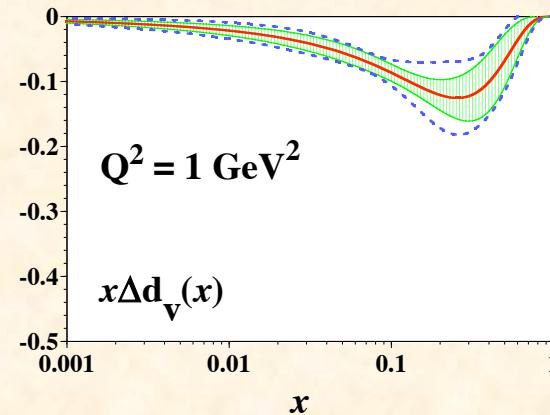
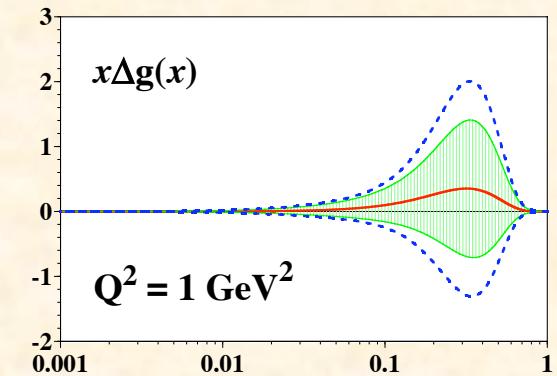
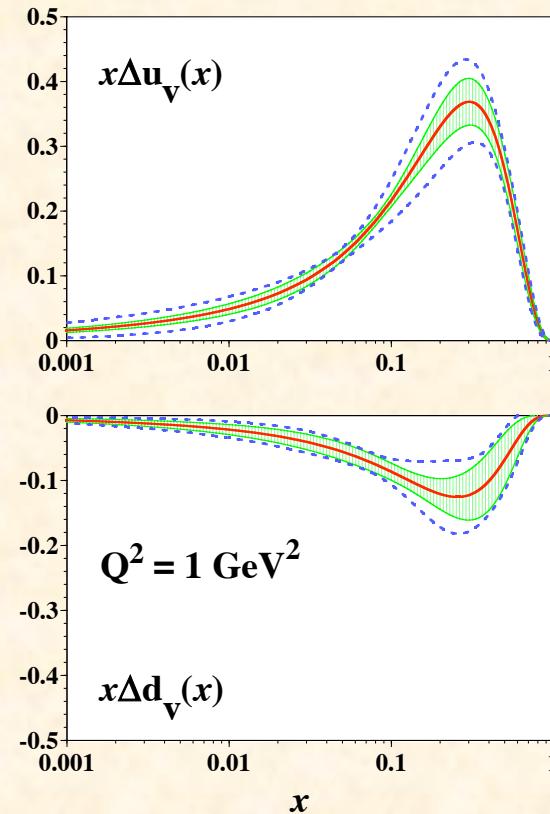
Polarized PDFs (AAC03)

- PDF uncertainties are reduced by including precise (E155-p) data
- Valence-quark distributions are well determined
 - Small uncertainties of Δu_v , Δd_v
- Antiquark uncertainty is significantly reduced
 - $g_1^p \propto 4\Delta u_v + \Delta d_v + 12\Delta \bar{q}$
- $\Delta g(x)$ is not determined
 - Large uncertainty
 - Indirect contribution to g_1^p
 - Correlation with antiquark

AAC03 uncertainties

..... AAC00 uncertainties

AAC00 \leftrightarrow AAC03 (with E155-p)



Correlation between $\Delta\bar{q}(x)$ and $\Delta g(x)$

- analysis with $\Delta g(x)=0$ at $Q^2=1 \text{ GeV}^2$

– $\chi^2/\text{d.o.f.} = 0.915$

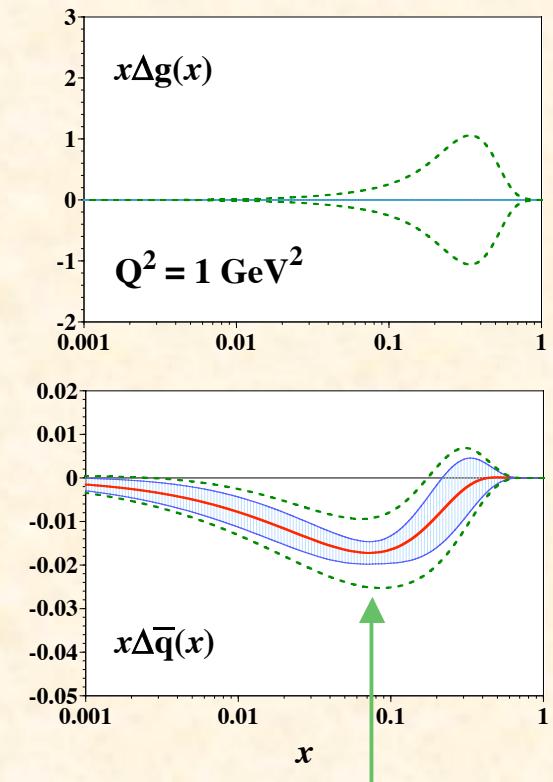
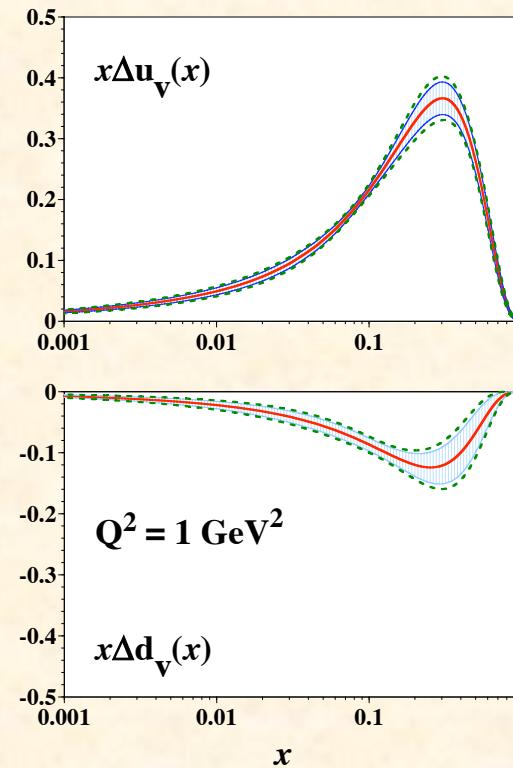
- $\Delta q_v(x)$ uncertainties are not affected

- antiquark uncertainties are reduced
 - strong correlation with $\Delta g(x)$

Note: correlation with $\Delta g(x)$ is almost terminated in the $\Delta g=0$ analysis

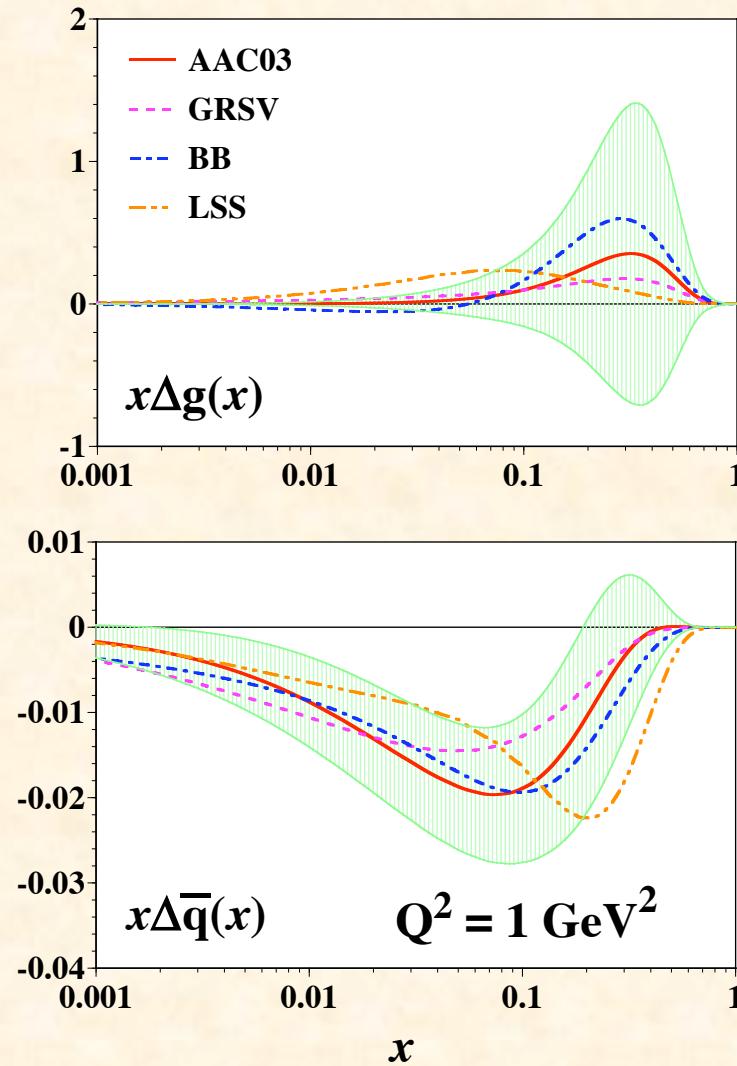
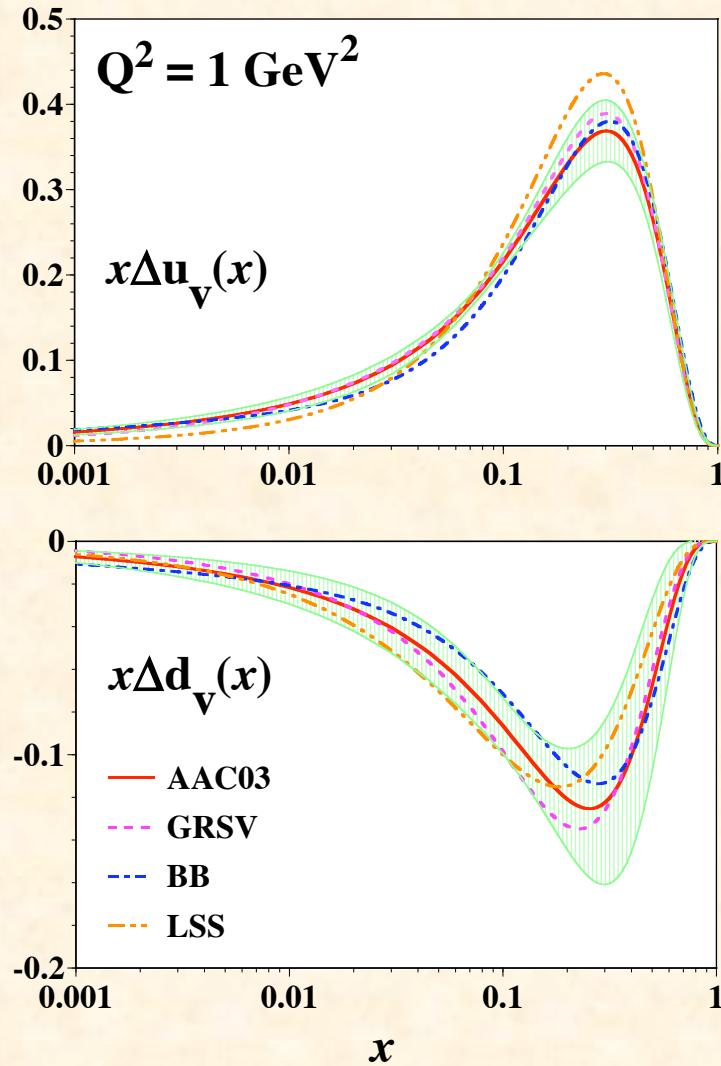
$\Delta g=0$ uncertainties

AAC03 uncertainties



The error band shrinks due to the correlation with $\Delta g(x)$.

Comparison with other parameterizations



1st moments

$$Q^2 = 1 \text{ GeV}^2$$

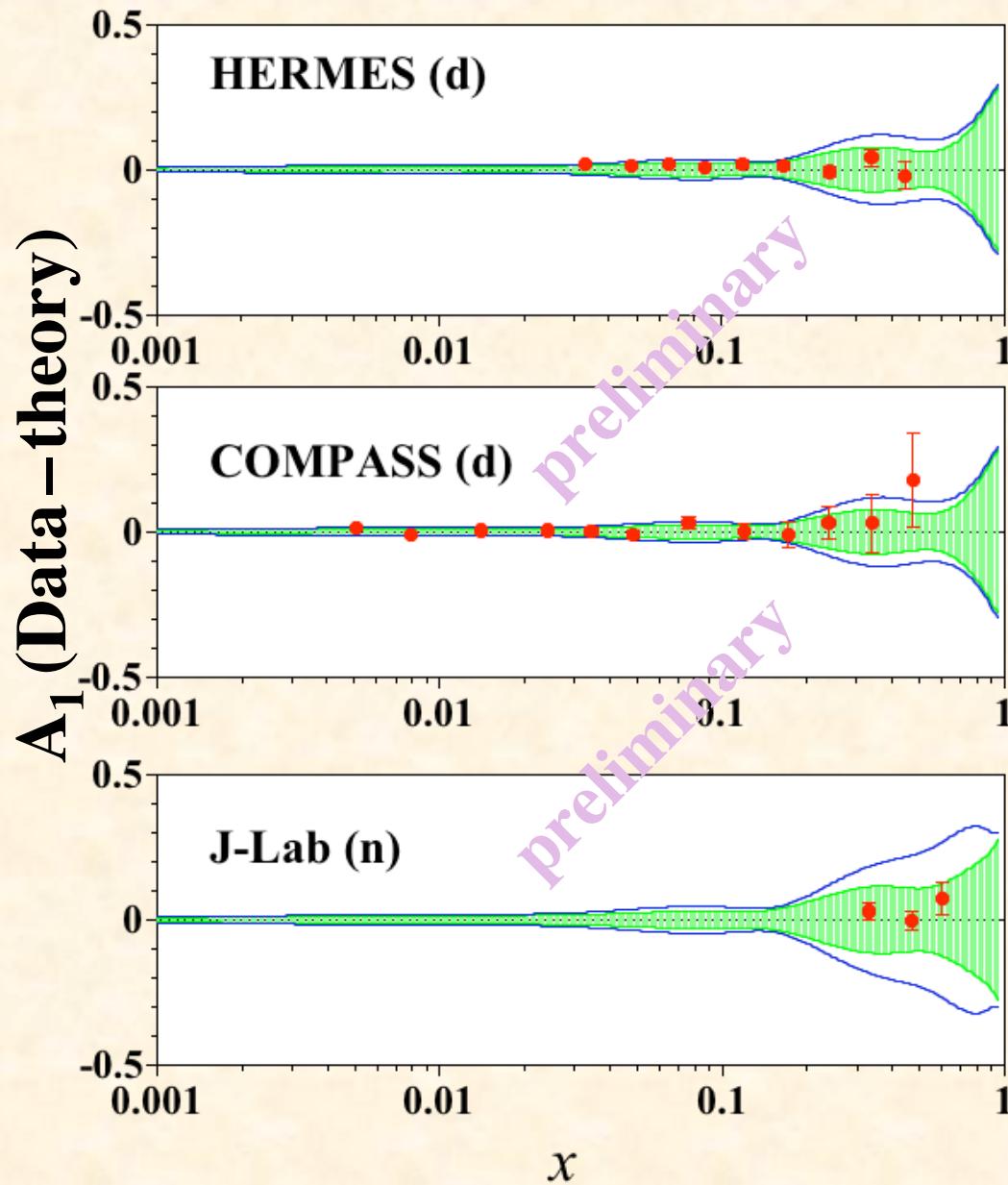
$$\left(\Delta\Sigma = \Delta u_v + \Delta d_v + 6\Delta \bar{q} \right)$$

	Δg	$\Delta\Sigma$
AAC03	0.499 ± 1.268	0.213 ± 0.138
GRSV01	0.420	0.204
LSS	0.680	0.210
BB	1.026	0.138

- GRSV01(Sta) [Phys. Rev. D63 (2001) 094005]
- LSS01 (MS) [Eur.Phys.J. C23 (2002) 479]
- BB02 (SET3) [Nucl. Phys. B636 (2002) 225]

**New analysis is in progress with
HERMES (d), COMPASS (d), and J-Lab (n) data**

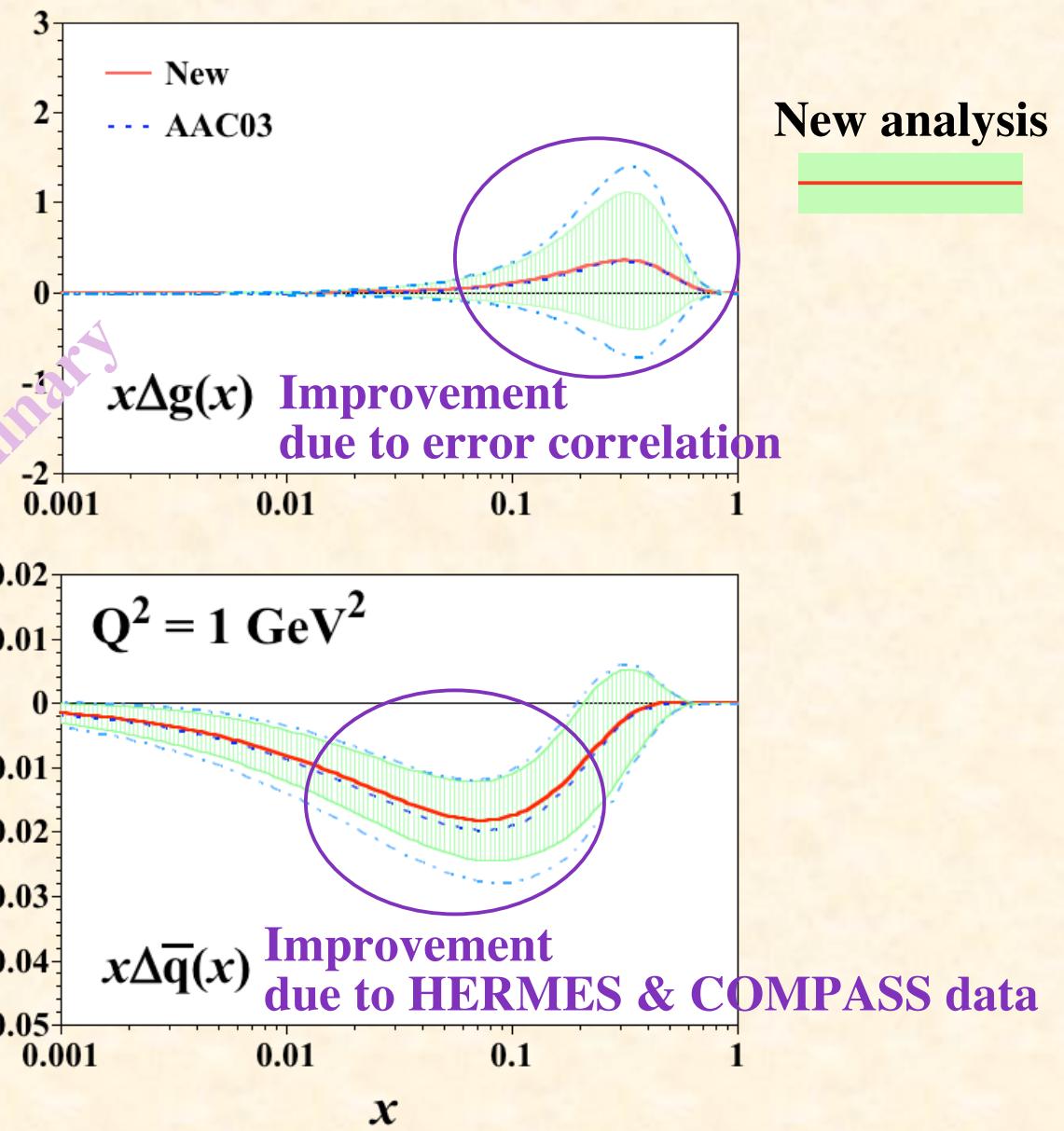
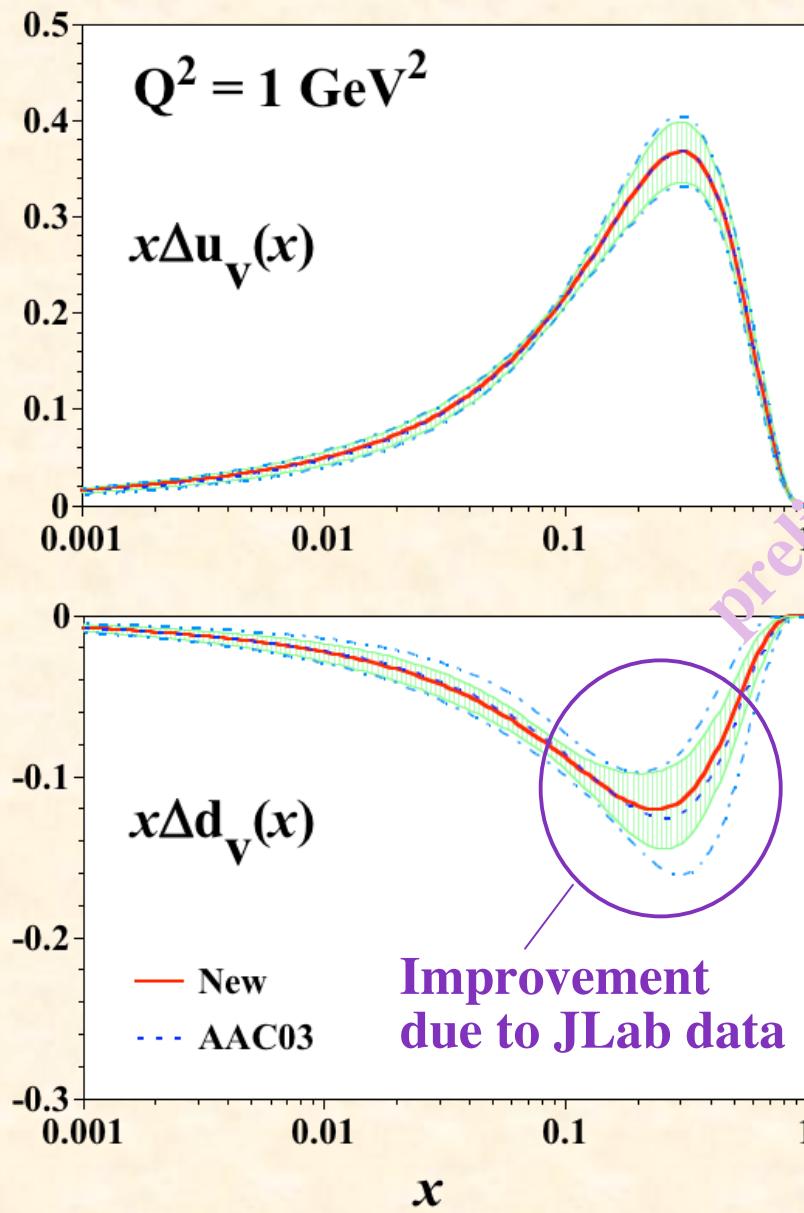
New analysis with HERMES (d), COMPASS (d), and J-Lab (n) data



— AAC03 uncertainties
■ New analysis

HERMES, COMPASS, and JLab data reduce the uncertainties.
In particular, the JLab data improve the neutron uncertainties.

New analysis with HERMES (d), COMPASS (d), and J-Lab (n) data



Summary of the AAC analysis

- Global analysis for polarized PDFs
 - $\Delta u_v(x)$, $\Delta d_v(x)$ are determined well
 - $\Delta \Sigma = 0.213 \pm 0.138$ ($Q^2 = 1 \text{ GeV}^2$)
 - $\Delta g(x)$ could not be constrained
- **Uncertainties of polarized PDFs**
- **Effects of E155-proton data**
- **Global analysis also with $\Delta g=0$**
- **Error correlation between Δg and Δq**
- **(in progress) New analysis with HERMES,
JLab, COMPASS data**

**AAC03-polarized-PDF code could be obtained from
<http://spin.riken.bnl.gov/aac/>**